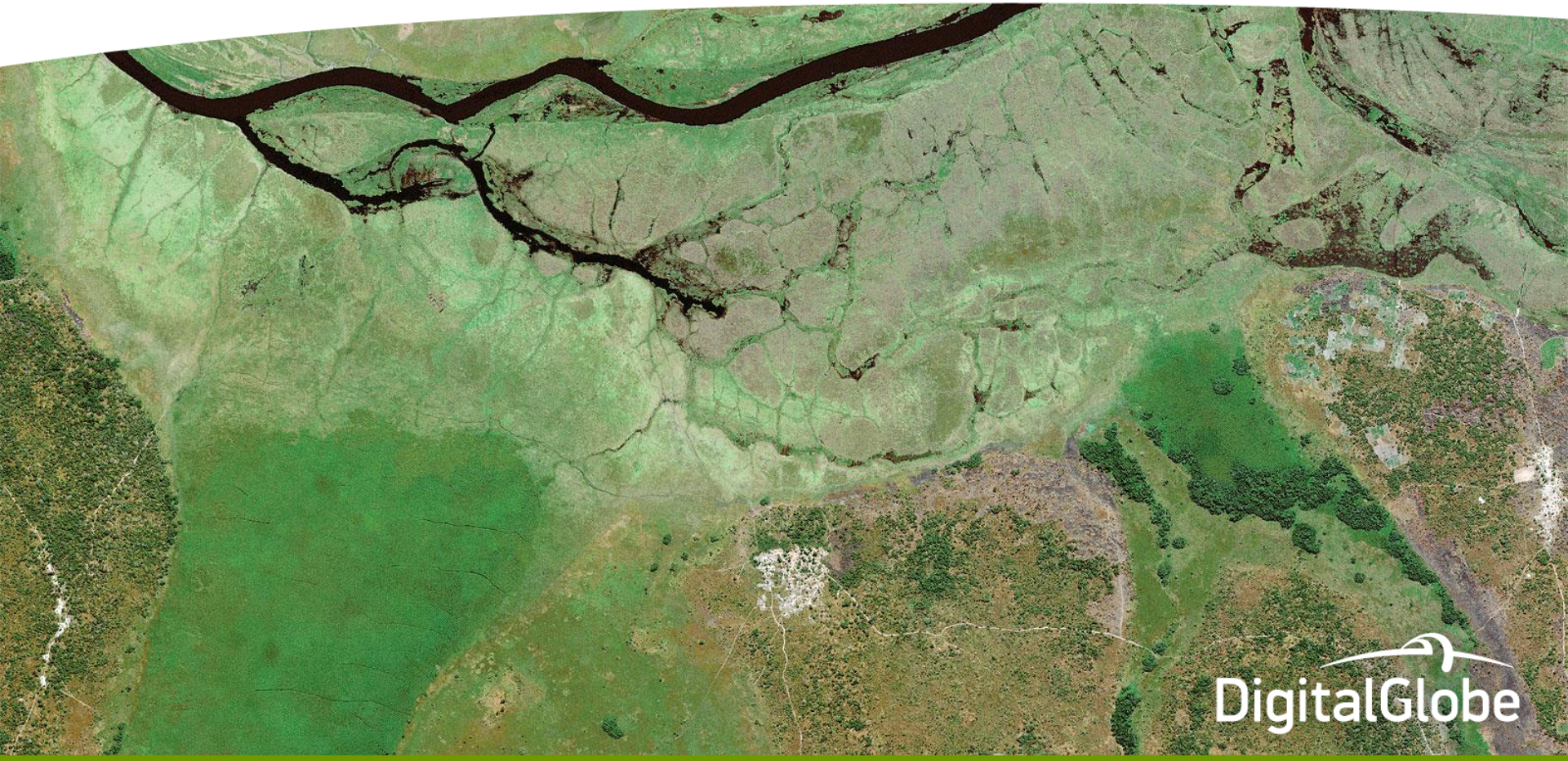
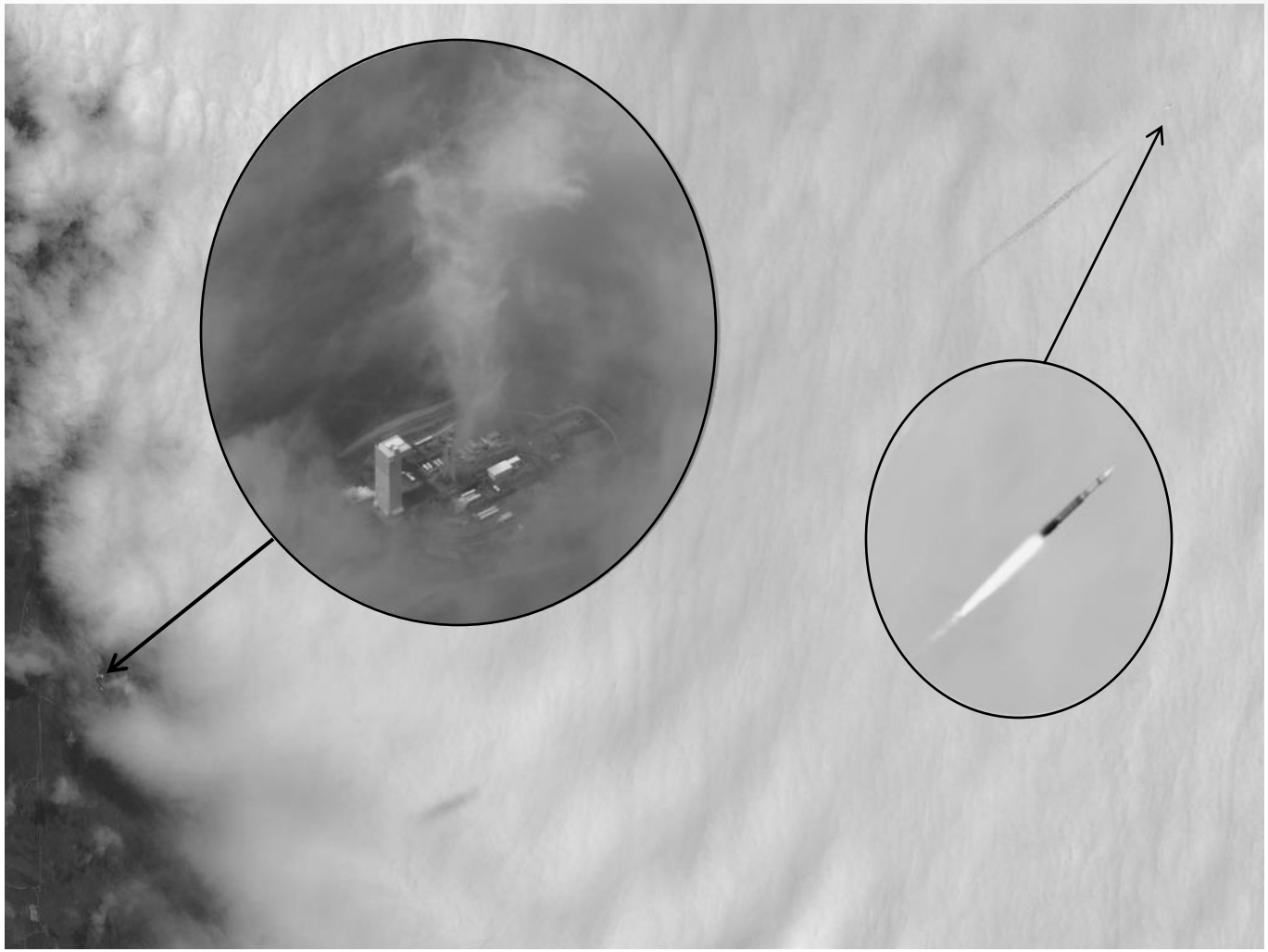
DigitalGlobe WorldView-3 SWIR Instrument Calibration and Applications

Chris Comp, David Mulawa, Nancy Podger, Bill Baugh



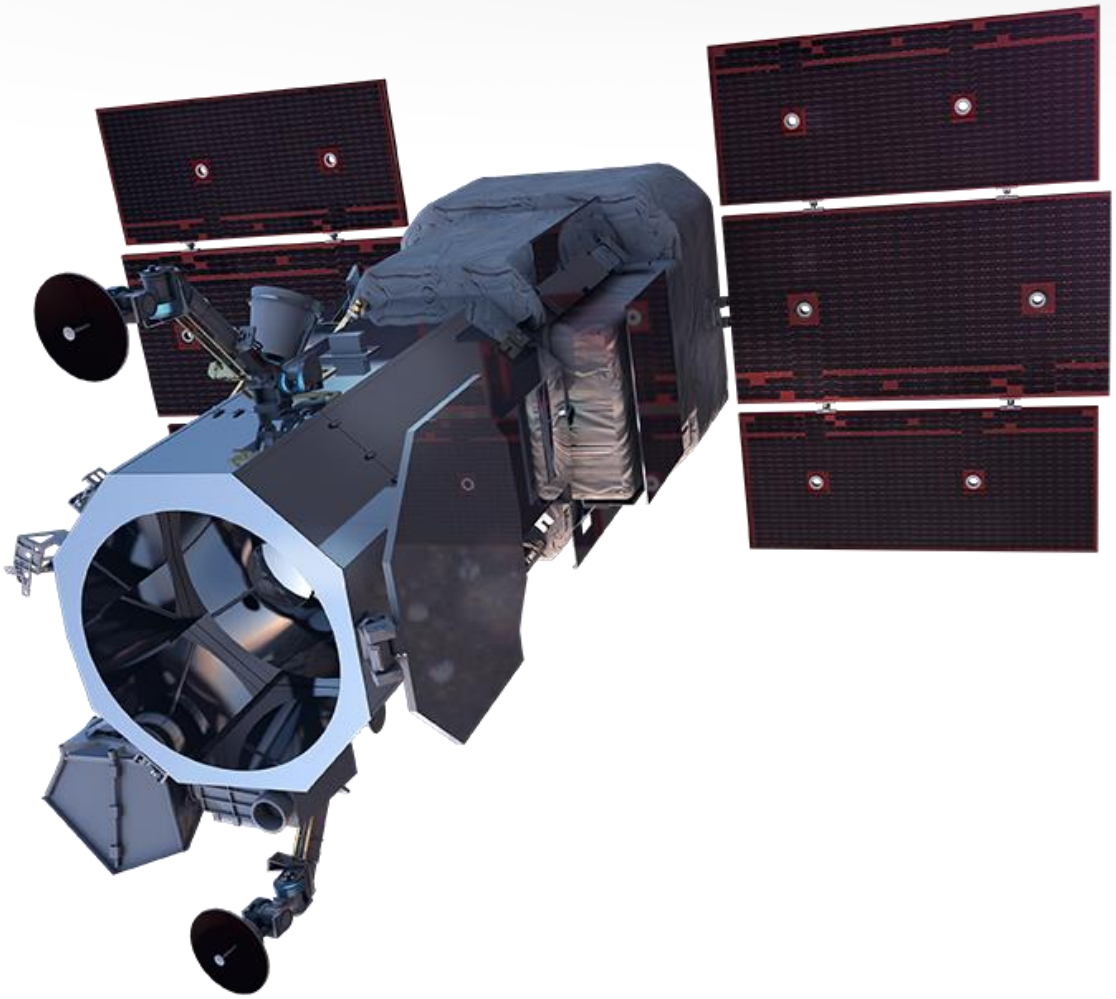
WorldView-3 Satellite Launch

- August 13, 2014 Vandenberg AFB
- Captured with WorldView-1 shortly after leaving launch pad

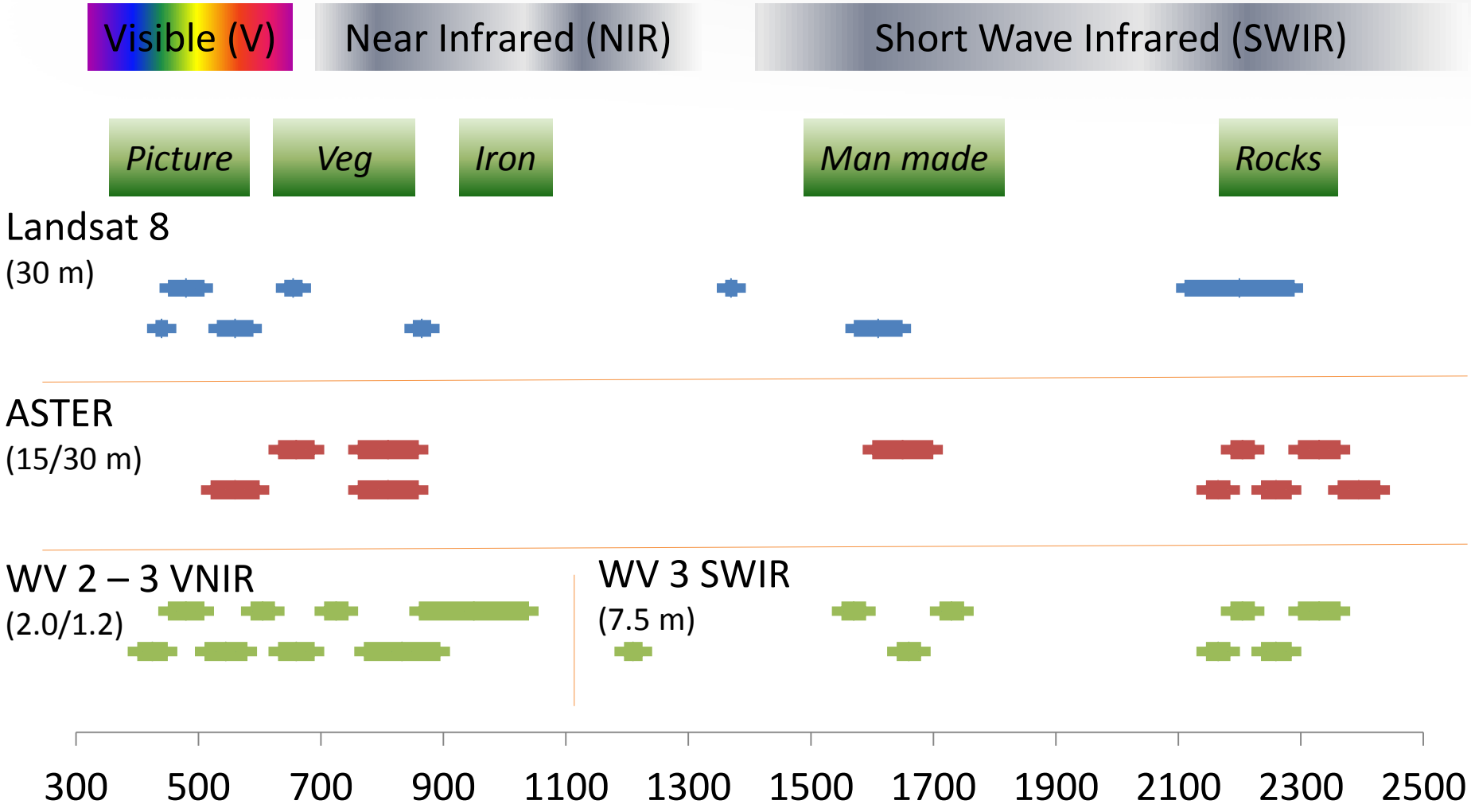


WorldView-3 Overview

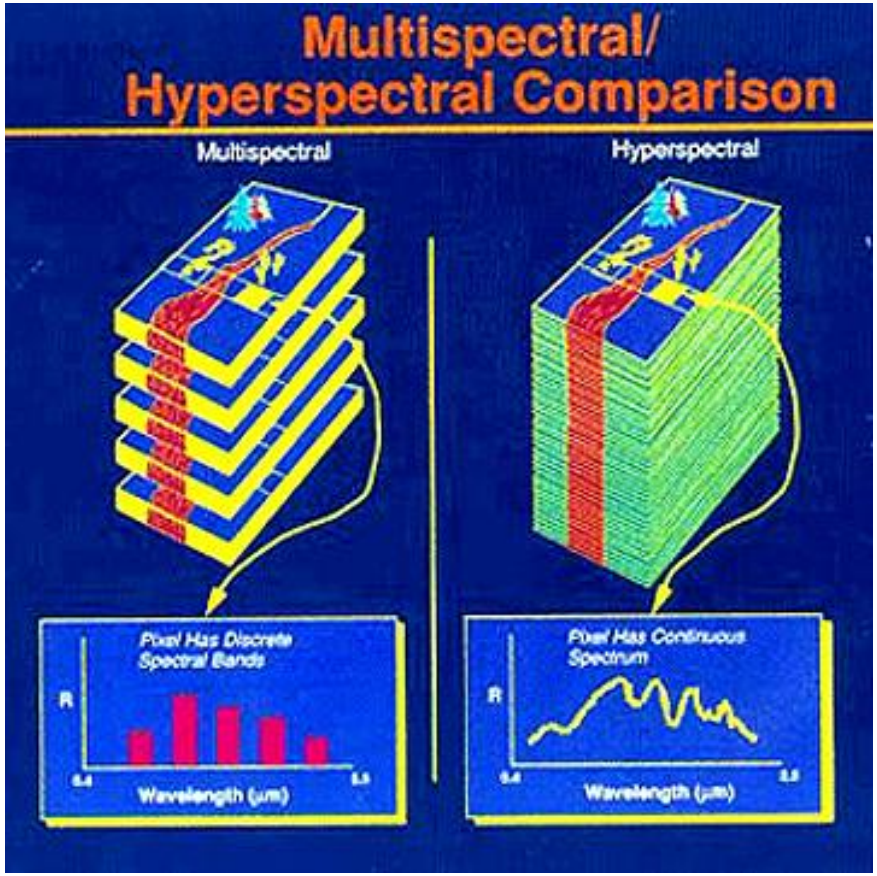
- 617 km sun-synchronous orbit
- Daily revisit capability
- Collects 680,000 SqKm imagery per day
- Three Instruments:
  - VNIR
    - Panchromatic 0.31 m
    - 8-band Multispectral 1.24 m
  - SWIR
    - 8-band 3.7 m native
    - Resampled to 7.5 m
  - CAVIS
    - 12 bands 30 m



WorldView-3 VNIR & SWIR Band Comparison



Multispectral vs. Hyperspectral vs. Superspectral



Graphic Source: Wikipedia

Definitions

- *Multispectral*: Less than 10 broad spectral bands.
- *Hyperspectral*: Many (hundreds) of narrow contiguous bands.
- *Superspectral*: More than 10 spectral bands, typically narrower than multispectral.

Examples

- *Multispectral*: Landsat, GeoEye-1, WorldView-2
- *Hyperspectral*: Hyperion, AVIRIS
- *Superspectral*: WorldView-3, ASTER, MODIS

WorldView-3 SWIR Calibration Topics

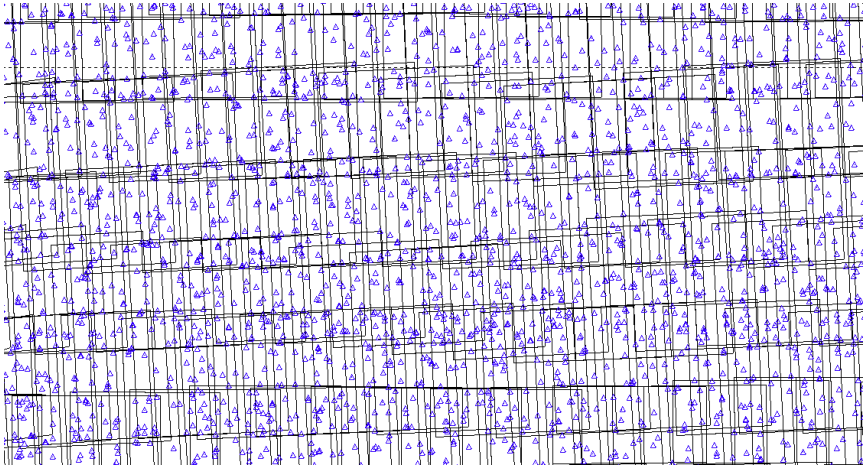
- Intra-sensor Geometric calibration
  - What: Field Angle Map calibration
  - Metric: SWIR band-to-band registration
- Inter-sensor Geometric calibration
  - What: Line-of-sight calibration between SWIR and VNIR
  - Metric: SWIR band to VNIR band registration
- Relative Radiometric Calibration
  - What: Uniform response for each spectral band
  - Metric: banding and streaking
- Absolute Radiometric Calibration: see Michele Kuester's Talk

Field Angle Map (FAM) Calibration Methodology

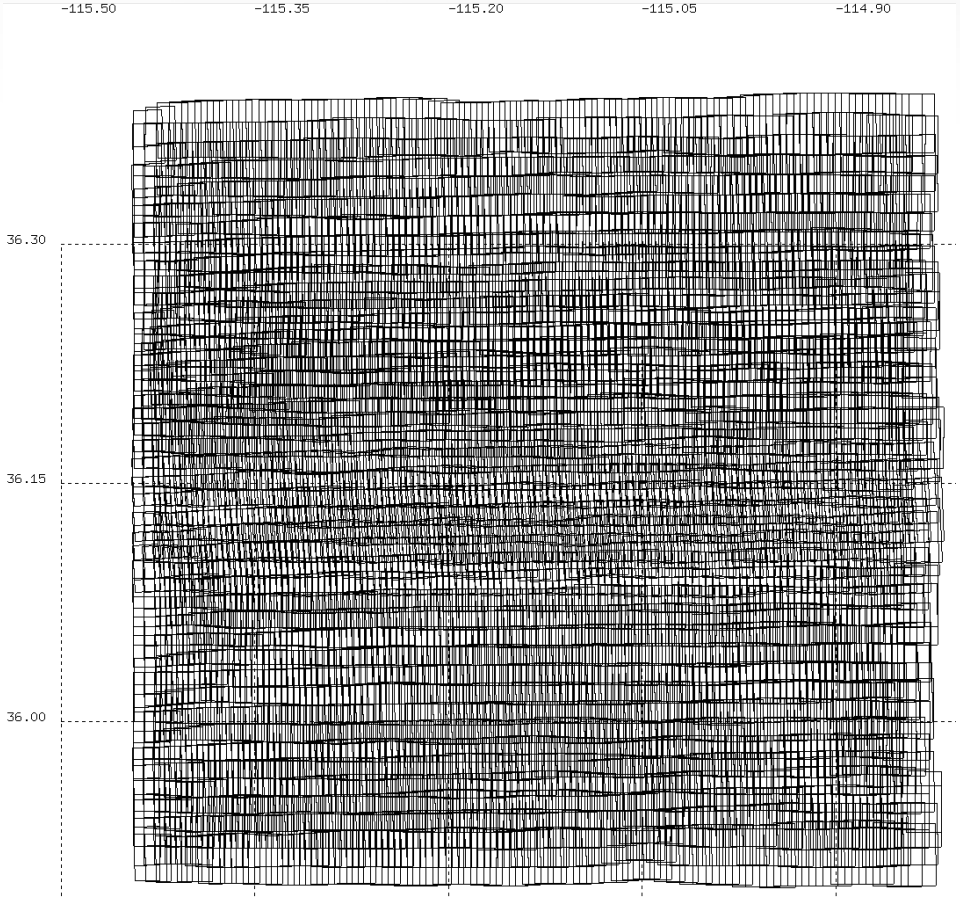
- Calibration Control
  - Digital aerial images collected with a strong geometry.
  - Controlled with a dense pattern of GPS surveyed photo identifiable control points.
  - Developed with a very dense set of object space tie points to be used as satellite calibration control points.
- Collection of satellite calibration imagery
  - Collection of multiple passes over several days to cover the extent of the operational FOV of the satellite.
- Calibration data measurement
  - Automated image correlation between the aerial control imagery and the satellite calibration imagery.
    - This leads to a massive number of photo rays, all of which have GCP values.
  - Correlated SWIR bands to each other for additional band-to-band registration observations.
- Calibration analysis
  - Optical distortion parameters are estimated in a Self Calibration Block Adjustment with Added Parameters.
  - A posteriori analysis of image residuals can be used to adjust detector positions on the focal plane.
- Calibration verification
  - Additional satellite imagery is collected and measured as above. Image residual analysis is performed.
  - Calibration parameters are used in image reconstruction and standard image products are made and tested.
  - Band to band registration is measured.
  - Visual inspection is used to look for sub-array shears.

Las Vegas Geometric Test Range

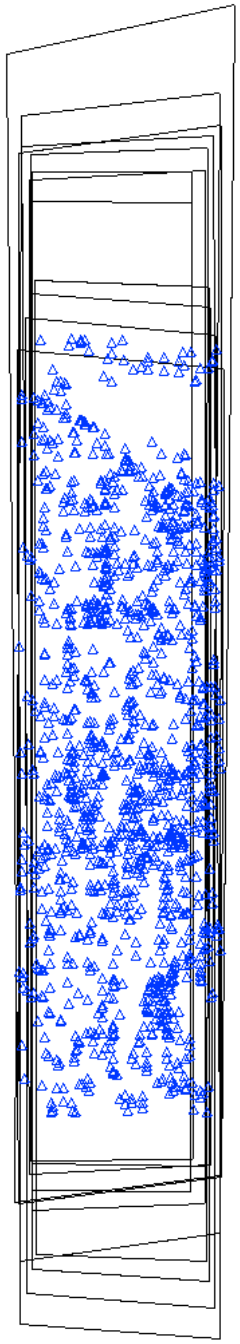
- Digital Aerial reference imagery from DMC camera
- 50km by 50km extent
- Ground Sample Distance of 30 cm



Detail showing object point density

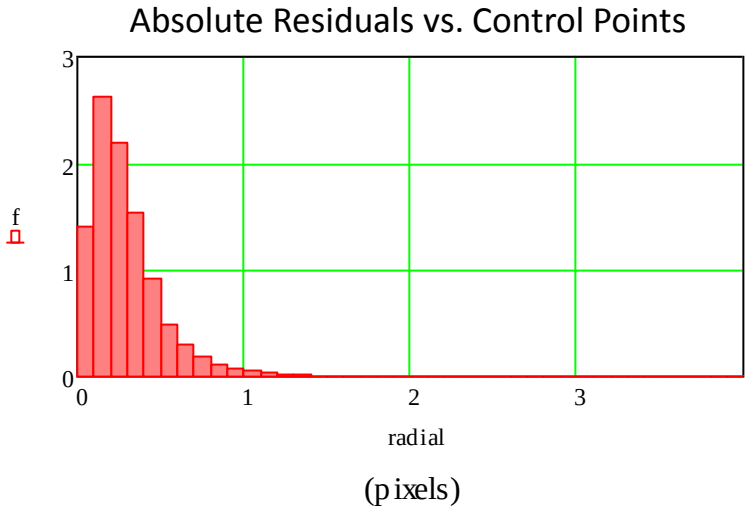


Footprint plot of the Las Vegas Range



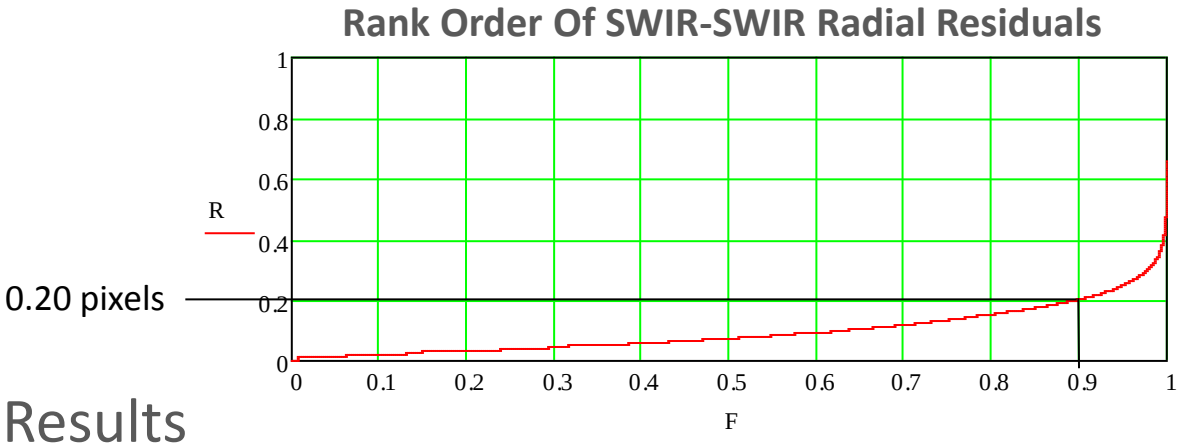
SWIR Image Strip Coverage Over Las Vegas Test Range

- Imagery used for calibration:
  - 12 strips collected on 2014 Sep 12, Sep 13, Oct 20, Oct 21 and Nov 15 over Las Vegas Test Range
  - Footprints and GCP pattern shown on left
  - There were 1,464 GCP and 13,853 tie points
  - There were 394,548 image point measurements
    - This is an average of 25.7 image points per object point
  - Post-calibration absolute residuals
    - Std Dev = 0.26 pixels
    - CE90 = 0.56 pixels
    - Includes errors from
      - Image registration
      - Attitude, ephemeris
      - Projection model
      - Control-point
      - Image-to-image differences



SWIR Band-to-Band Registration (Intra-sensor)

- Method of Evaluation
  - Used autocorrelation methods to measure matching points within SWIR bands of basic products
  - The differences in line and sample were computed for each point in each band pair
  - Radial distances were computed and then rank ordered (see graph)



- Evaluation Results
  - **CE90 for the set of all band pair combinations was 0.20 SWIR pixel**
  - Median value was 0.07 pixel
  - Includes effects of image matching errors

SWIR Band-to-Band Registration Variation By Band

Table shows SWIR band-registration by band pair (CE90 values in pixels)

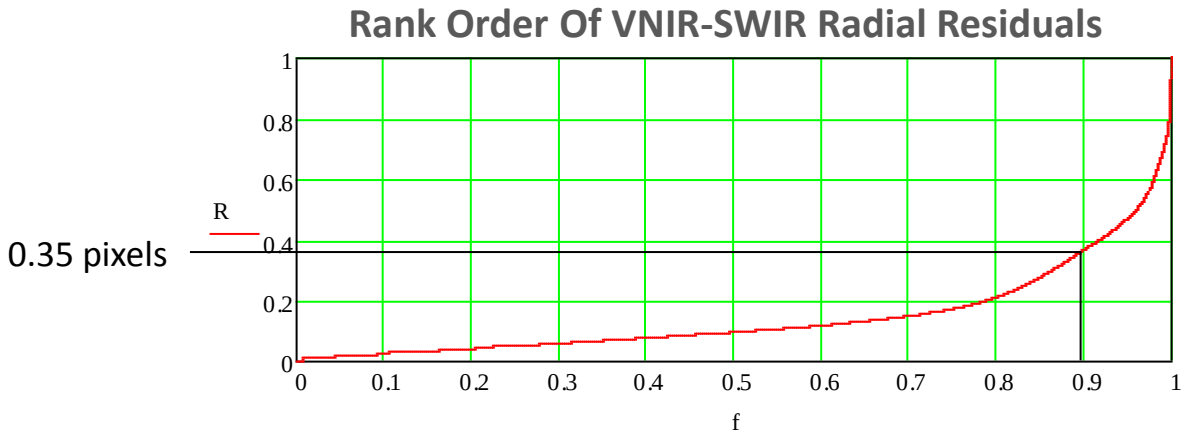
Variation among band pairs is due mostly to large size of SWIR focal plane and spectral differences

	S1	S2	S3	S4	S5	S6	S7	S8
S1	0.00	0.17	0.11	0.12	0.27	0.12	0.15	0.30
S2	0.17	0.00	0.11	0.10	0.19	0.11	0.12	0.27
S3	0.11	0.11	0.00	0.06	0.20	0.07	0.07	0.23
S4	0.12	0.10	0.06	0.00	0.20	0.06	0.07	0.22
S5	0.27	0.19	0.20	0.20	0.00	0.20	0.19	0.32
S6	0.12	0.11	0.07	0.06	0.20	0.00	0.07	0.20
S7	0.15	0.12	0.07	0.07	0.19	0.07	0.00	0.20
S8	0.30	0.27	0.23	0.22	0.32	0.20	0.20	0.00

For example, band S7-S5 registration = 0.19 pixel CE90

SWIR-VNIR Band Registration (Inter-sensor)

- Method of Evaluation
  - Used autocorrelation methods to measure matching points between VNIR and SWIR imagery basic products
  - The differences in line and sample were computed for each point in each band pair
  - Radial distances were computed and then rank ordered (see graph)



- Evaluation Results
  - **CE90 for the set of all band pair combinations was 0.35 SWIR pixel**
  - Median value was 0.10 pixel
  - Includes effects of image matching errors

Relative Radiometric Calibration Specification

- Purpose: Detector equalization to reduce pixel-to-pixel (streaking) and sub-array to sub-array (banding) variations.

- The relative radiometric calibration product specification for 95% products is:
  - < 10% of dynamic range there shall be no streaking or banding metric specification
  - 10% < of dynamic range < 20% banding and streaking metrics shall not exceed 2
  - >20% < of dynamic range < 85% banding and streaking metrics shall not exceed 1%
  - > 85% of dynamic range there shall be no streaking or banding metric specification

- If a detector cannot meet this specification then it is considered a failed pixel and not used in image reconstruction.
  - The 8 band SWIR sensor has 28800 detectors and DigitalGlobe has failed 10 detectors, or 99.965% of the pixels are within specification.
  - For a failed pixel, the average value of its neighboring detector is used to replace the value of the failed pixel.

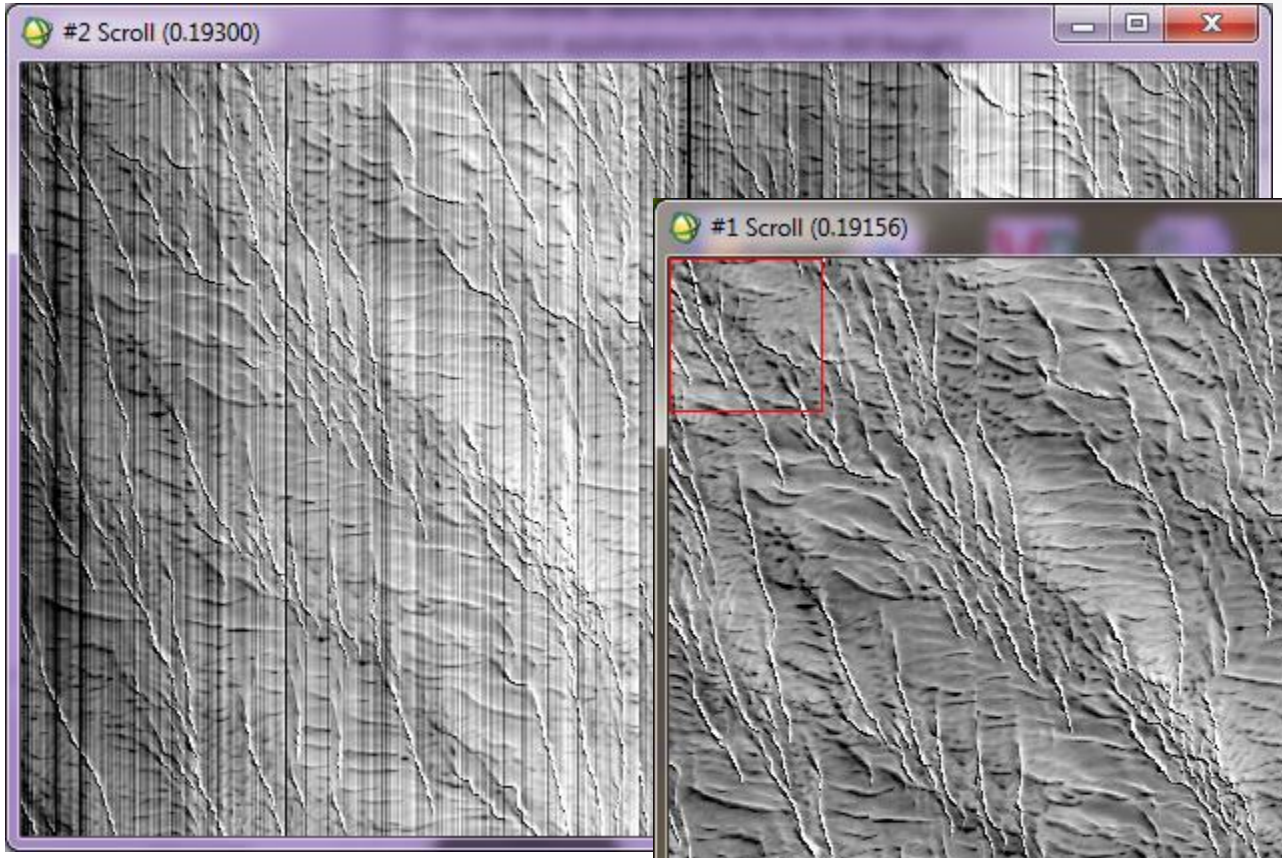
Relative Radiometric Calibration Methodology

- Detector dark response
  - Data is acquired by imaging the night skies where no celestial bodies can be sensed.
  - The dark level for each detector is the average value of the scan line acquired by a detector.

- Detector gain
  - Gain curves are calculated using numerous images of relatively homogeneous land cover.
  - DigitalGlobe uses 35 target locations worldwide for this calibration.
  - Collected calibration images must be cloud-free, glint free, saturation free.
  - The gain for a single detector is the average all the scan lines within an image. The average of all the detectors is used as truth or target value for that scan.
  - Numerous homogenous scans are used to reduce the noise and obtain a representative depiction of the detector gain for the entire dynamic range.

- Calibration verification
  - Streaking = measure of pixel-to-pixel variation
  - Banding = measure of sub-array to sub-array variation
  - Streaking and banding metrics are calculated across the focal plane on homogeneous images not used to create the calibration parameters.
  - Banding is sampled manually in homogeneous areas of adjacent sub-arrays.
  - Visual inspection of images – the human eye is very good at picking out linear features.

Relative Radiometric Calibration Example



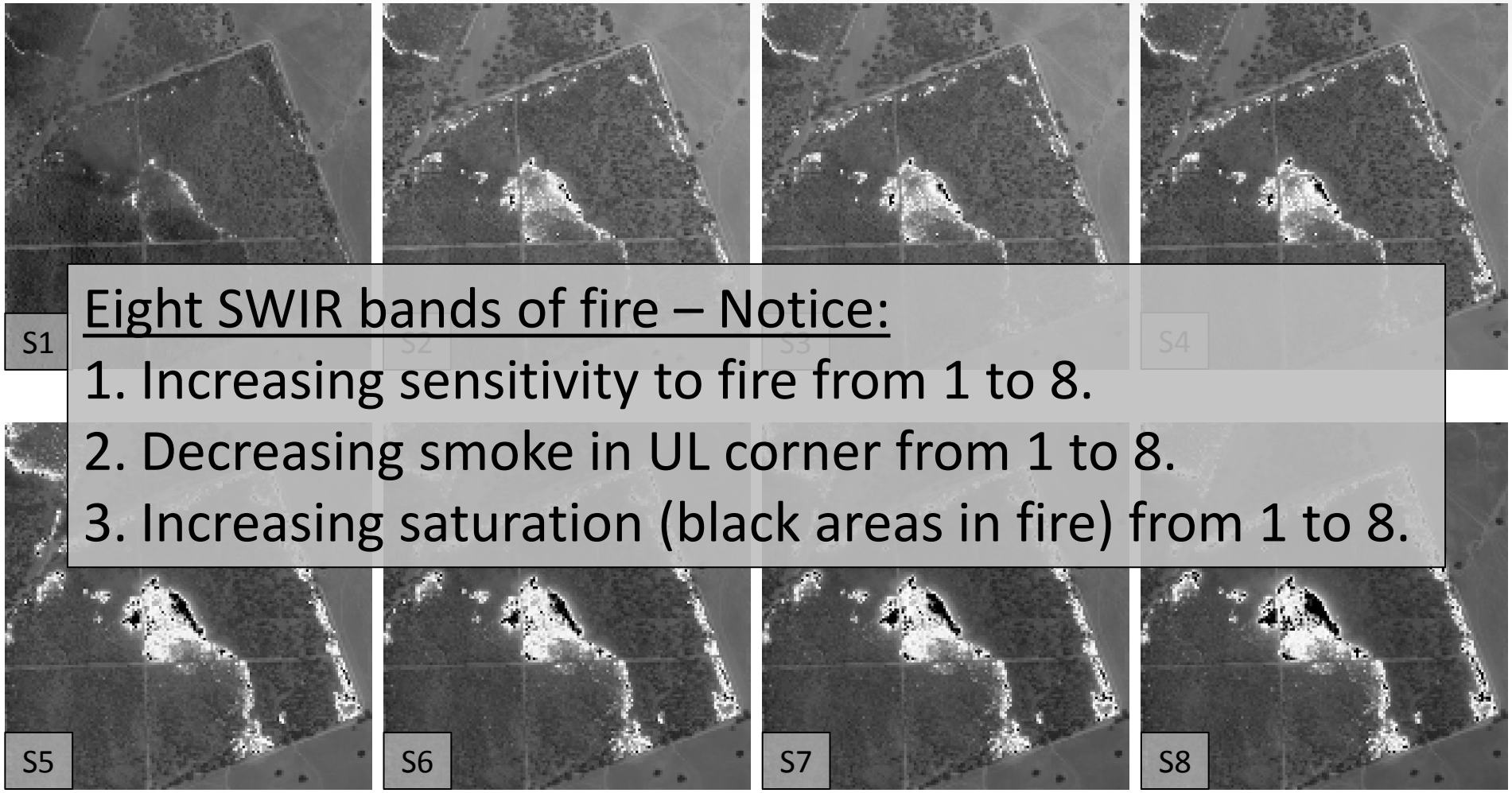
SWIR Band-2, Precalibrated

SWIR Band-2, Calibrated

WorldView-3 SWIR Applications

- Thermal + Smoke Penetration + Fire
- Geology + Minerals + Classification
- Maritime + Wake Detection
- Many others not covered here
  - See www.DigitalGlobe.com for more information
  - Contact Bill Baugh wbaugh@digitalglobe.com

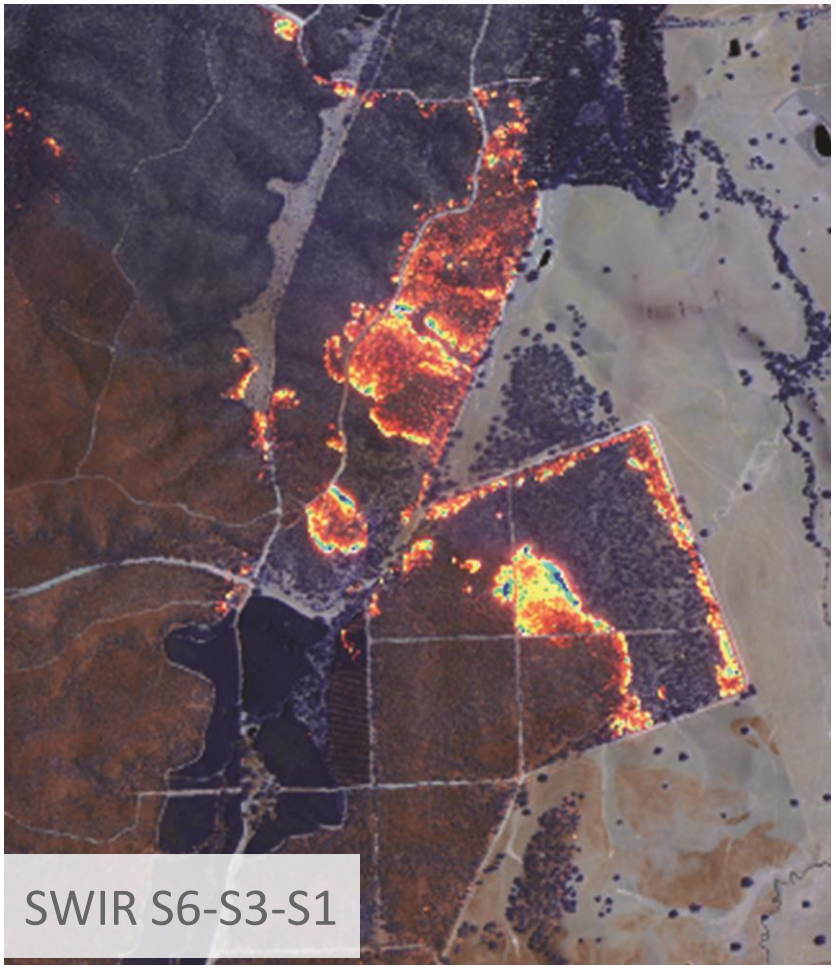
SWIR Band Sensitivity: Thermal/Fire



Eight SWIR bands of fire – Notice:

1. Increasing sensitivity to fire from 1 to 8.
2. Decreasing smoke in UL corner from 1 to 8.
3. Increasing saturation (black areas in fire) from 1 to 8.

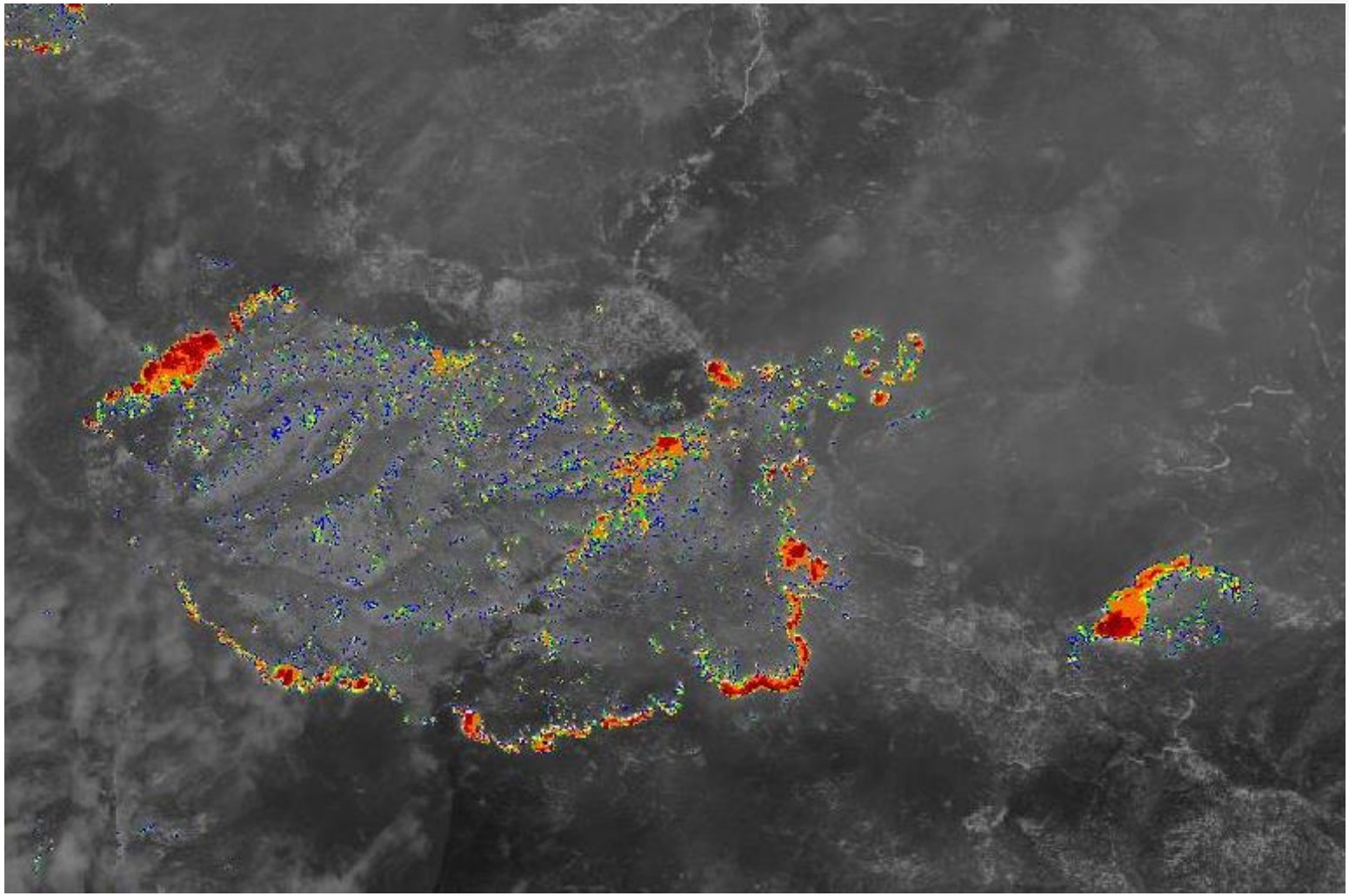
WorldView-3 Color vs. SWIR for Thermal/Fire



Wildfire smoke in color image (WV-3 VNIR R-G-B)

Wildfire smoke penetration in SWIR S6-S3-S1

Wildfire smoke penetration + heat map in SWIR

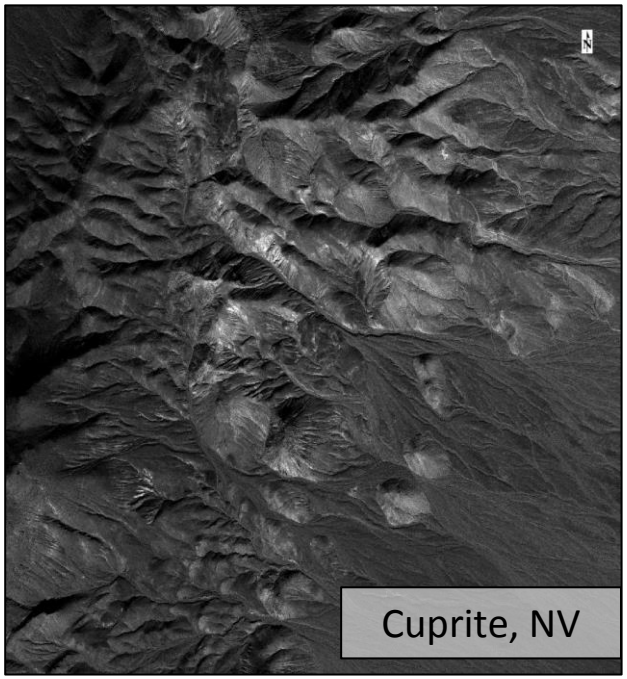


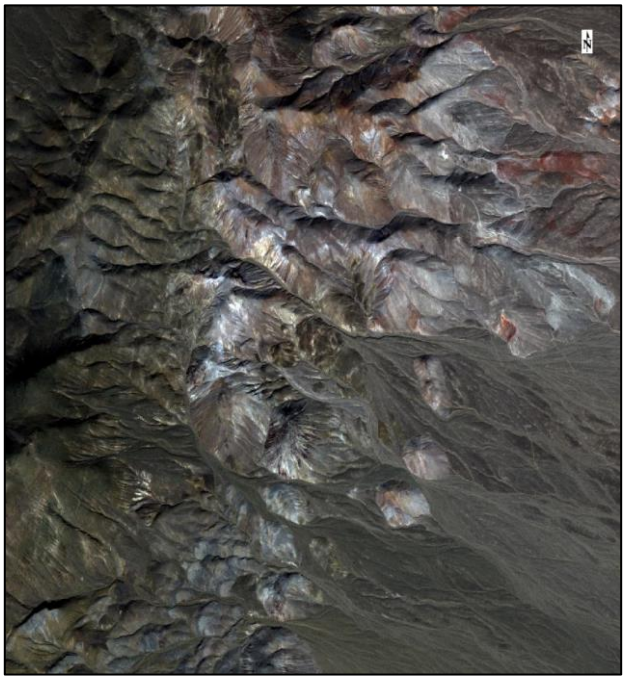
Band Combinations for Ore/Mineral Mapping

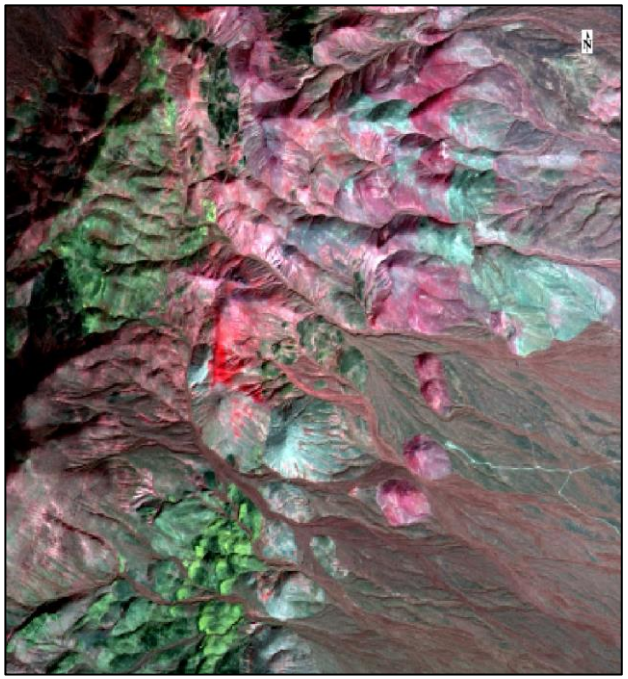
WorldView-1

WorldView-2/3

WorldView-3 SWIR







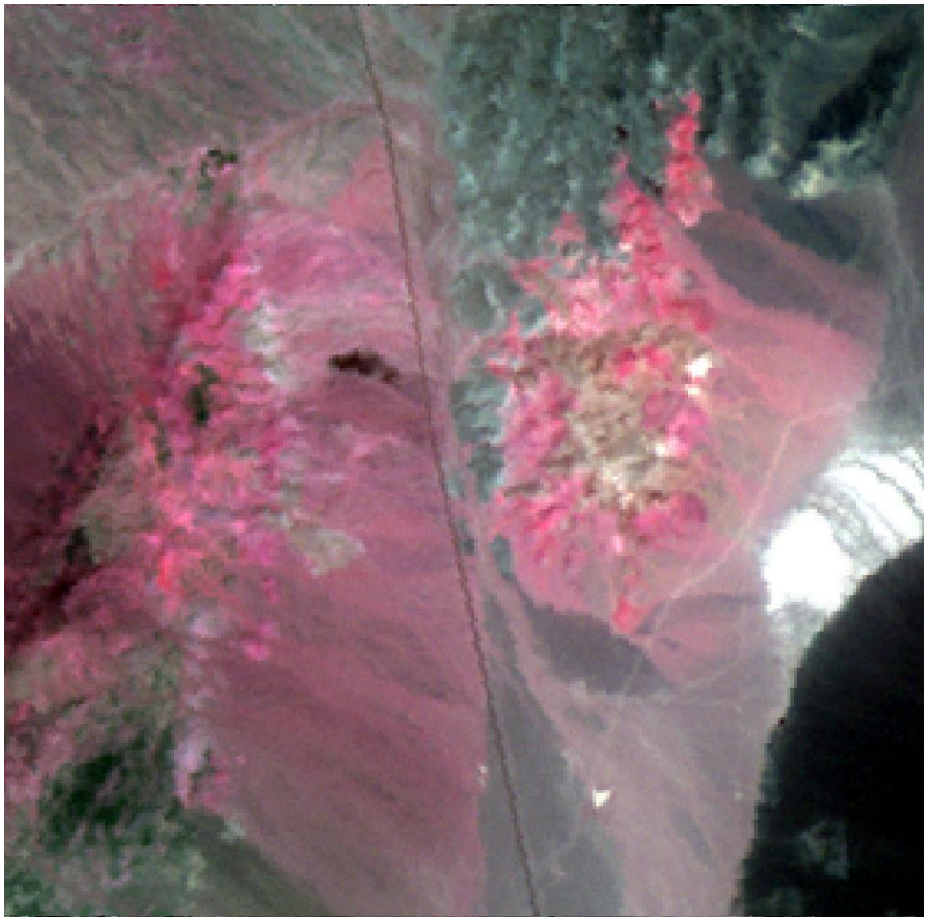
Panchromatic

Color 5-3-2

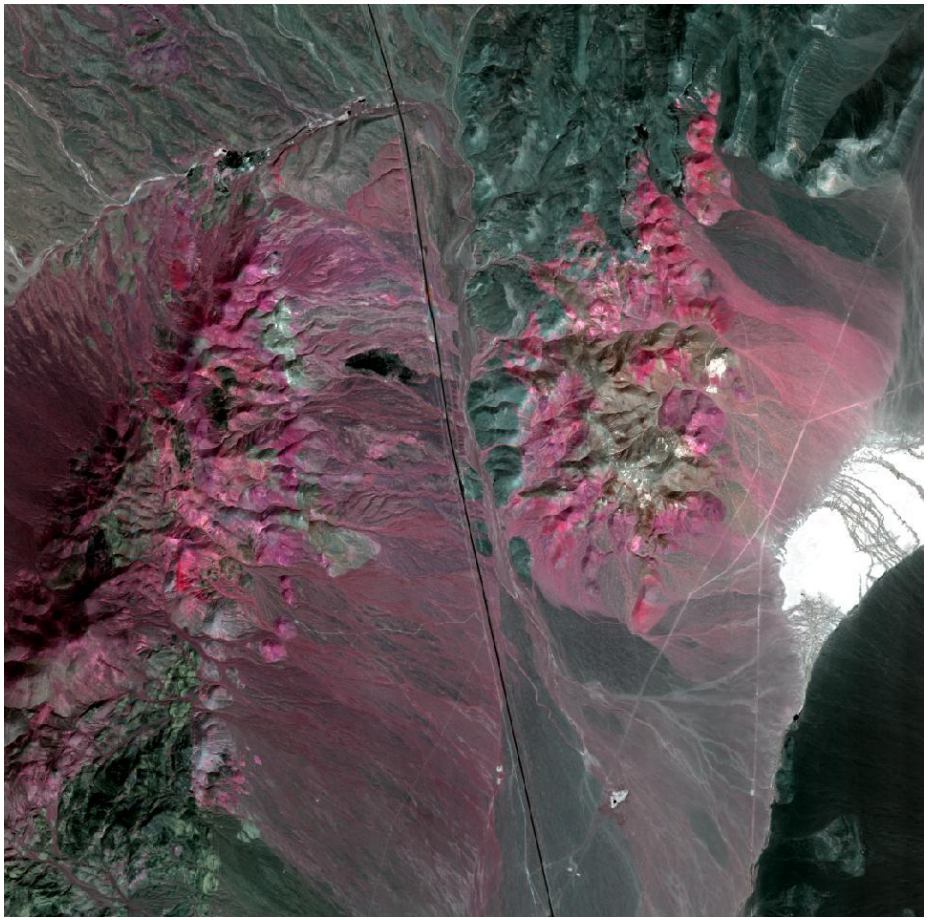
SWIR S3-S6-S8

WorldView-3 SWIR Complements Other SWIR Sensors

ASTER: 4-6-7 | 30 m pixels

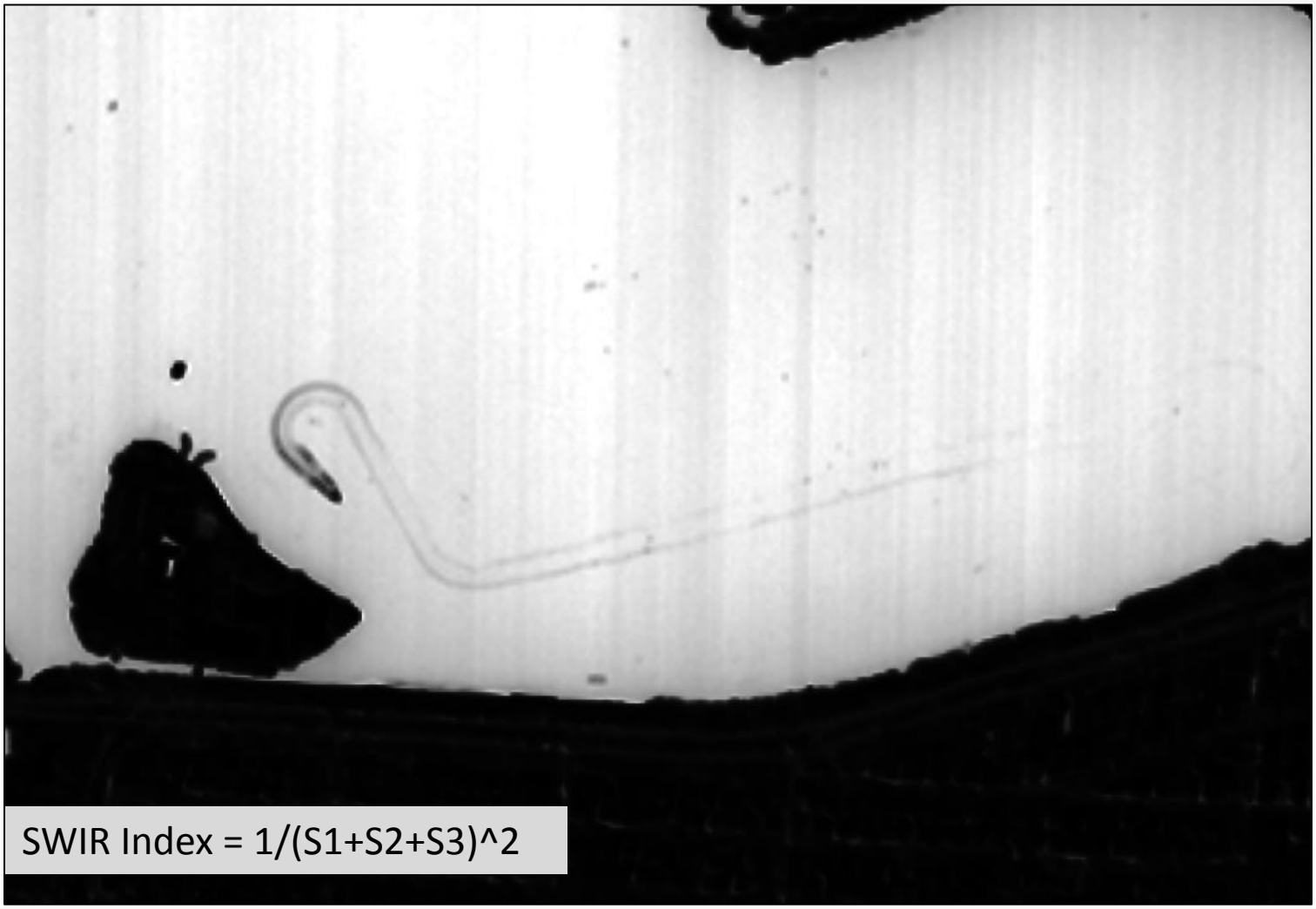


WV-3 SWIR: S3-S6-S7 | 7.5 m pixels



Maritime Image Using WorldView-3 Color: Pretty

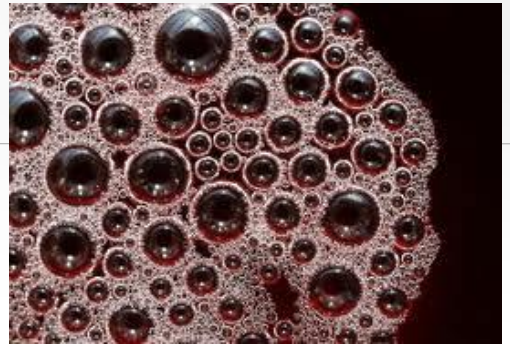
WorldView-3 SWIR Wake Detection: Cool



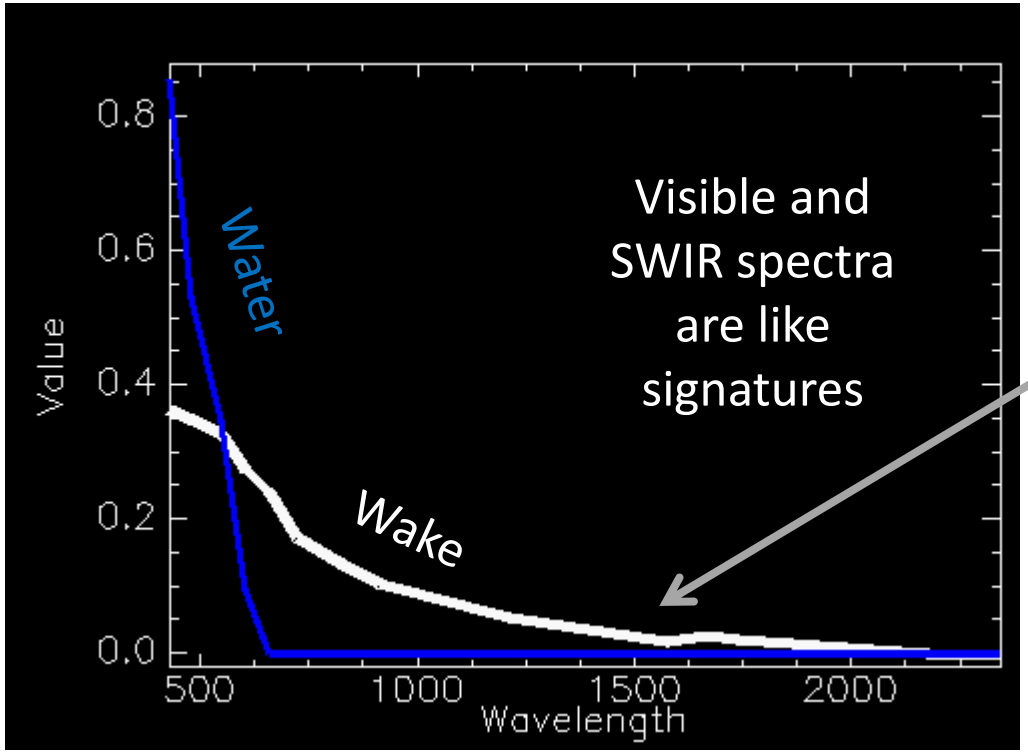
Maritime SWIR applications

What's Happening?

*Water absorbs infrared, but water **bubbles** reflect!*



The computer finds pixels that have spectra similar to the unique wake signature.



The long SWIR 'tail' on the wake is distinctive.

Water's flat near-zero values in the NIR and SWIR is distinctive.

Final Words

- WorldView-3 Offers Superspectral Imaging
  - 8 VNIR-MS bands at 1.2 m GSD
  - 8 SWIR bands at 7.5 m GSD
- SWIR Advantages
  - SWIR penetrates smoke (not clouds)
  - SWIR has thermal response
  - SWIR tells us about materials
- WorldView-3 7.5 m SWIR Complements Other Sensors
  - Detailed targeting and classification vs. large-area mapping
  - Rapid response to critical events with daily revisit
- Future DigitalGlobe Supercube Product
  - Stack all VNIR-MS and SWIR bands into a 16-layer cube
  - All bands resampled to a common pixel dimension
  - All bands co-registered
  - Atmospheric compensation resulting in surface reflectance

Thanks to the DigitalGlobe Cal-Val Team

- Geometric Calibration
  - Brendan Clarke
  - David Mulawa
  - Kevin Harrison
  - Ryder Whitmire
  - Woodson Bercaw
  - Chris Comp

- Radiometric Calibration
  - Nancy Podger
  - Michele Kuester
  - Todd Updike